Pulsed Plasma Nitriding of Titanium and Titanium Alloys

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Abstract

Plasma surface treatment is now well established as a flexible, cost effective alternative to salt bath and gaseous nitriding. The high level of flexibility and reproducibility achieved by pulsed plasma nitriding provides many opportunities for users to improve performance and reduce life cycle costs.

1 Introduction

Nitriding to enhance the wear, friction, fatigue and/or corrosion properties of production tools and components made of ferrous alloys is widely applied throughout industry and the high level of flexibility and reproducibility achieved by modern plasma surface treatments provides many opportunities for end users to improve performance and reduce life cycle costs.

Since introducing the pulsed plasma into industrial heat treatment a broad range of applications for titanium alloys is also possible.

2 Pulsed Plasma Nitriding

With conventional dc plasma operation, overheating of thin sections can occur due to the voltages and current densities required to obtain a glow discharge that completely surrounds the workpiece. Localised heating can further concentrate the energy input from the plasma in such areas, leading to arcing, which damages the surface finish.

Within deep slots or narrow openings, there is a possibility of workpiece melting via the ‘hollow cathode effect’: therefore the treatment of titanium or titanium alloys was restricted to very simple geometries. Otherwise big problems with distortions are obtained.

The Eltropuls system solves the overheating problem by decoupling the heating and surface treatment functions, limiting the plasma energy input to that required to affect the metallurgical changes sought. This is achieved by replacing the steady state plasma with spiked current and voltage pulses (see Fig.1 – Ignition pulse system).

Nitriding, with an ion density determined by the voltage amplitude, is thus accomplished without significant heating from the plasma, temperature control being provided independently by resistance elements. The pulse duration, of the order of microseconds, reduces the heat input. Duty cycles during which the pulse is on for only 10 – 50 % of the cycle do not appear to have any effect on nitrogen activity or nitriding time and the nature of the cycle can be varied during treatment to produce microstructures with the required features. The pulsing effect on the heat input is shown in Fig.2.

3 Nitriding of Titanium and Titanium Alloys

Nitriding is a thermo-chemical heat treatment process introducing nitrogen into the outermost surface of parts and components. The process time is diffusion controlled.

Due to this reason a compromise of nitriding temperature has to be found. To realise short cycle times the highest treatment temperature is of interest. High temperatures lower the hot strength of the material and results in distortions. Therefore high temperatures are only recommended for parts and components with a simple geometry. In any case a direct temperature measurement on a real component or part is required. Fig.3 shows the time and temperature dependence on the layer of TiN. Typical layer thicknesses for the most applications are in the range of 1 – 3 µm.

Such layers generated by a diffusion process are showing surface hardnesses of 900 - 1100 HV0,05.

Due to a growing of the layer from the bulk material there is no danger of the layer spalling off as in case of PVD treatments. Furthermore a diffusion zone supports the TiN layer. The typical layer thickness of the diffusion zone is 20 - 40 µm. Due to the small layer thickness pulsed plasma nitriding results in an improvement of adhesive wear only. The lattice structure of TiN avoids adhesion in case of contact of two components made of titanium if one of these is nitrided.

Also the wear in case of contact with other materials can be reduced by pulsed plasma nitriding.

An improvement of fatigue properties as in the case of steel nitriding isn't observed. Specially too high nitriding temperature of titanium alloys (Ti6V4) results in a loss of toughness. High temperatures which gives thicker layers in shorter times are only recommended for applications where a primary improvement of wear is required. Nitriding causes a growth of the parts in the range of some µm because nitrogen is introduced into the surface. By changing the machining dimensions the mass growth can be compensated for Distortions are related to the treatment temperature, the time on temperature and of where the nitriding is required. In any case a uniform nitriding of all surfaces is recommended.

4 Applications

Lightweight alloys are widely used in aerospace, race car and medical applications. Pulsed plasma nitriding is widely used to provide adequate service performance from the point of tribological properties.

Fig.4 is showing a nitrided structure, etched in 2% HF. Fig.5 and 6 are showing two application in race car industries. For the valves and the steering rack the base material is Ti-6AI-4V.

Pulsed plasma nitriding results in a better wear resistance.

For example :- A formula one steering rack was PVD coated (TiN). The TiN layer only lasted one race. By changing to pulse plasma nitriding the lifetime was increased to 8 – 10 races, indeed the life was not limited because of wear but because the design fatigue life had been reached. Pulse plasma nitriding is also considered state of the art for the treatment of titanium valves. The appearance of titanium parts after pulsed plasma nitriding is a dark, dull golden colour, not a bright gold colour as with PVD coating.

To get a similar appearance, polishing is required.

The aesthetic appearance of plasma nitrided implants without polishing limits the number of applications compared to PVD TiN coatings, even though there is no danger of the layer spalling and the mechanical properties are higher.

5 Summary

Nitriding of titanium or titanium alloys can be used to improve wear resistance. Pulsed plasma nitriding lowers the heat input during treatment and allows now new fields of applications.

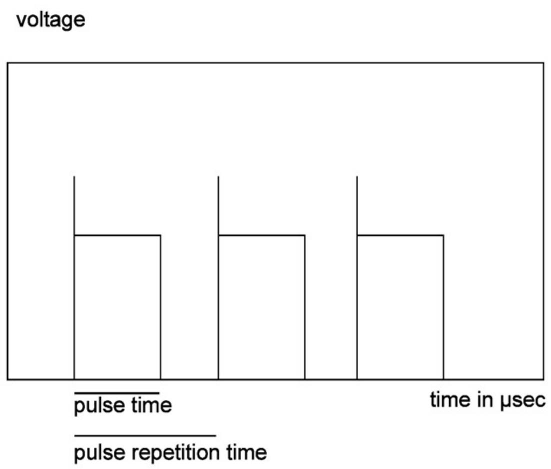

Figure 1: Ignition pulse system.

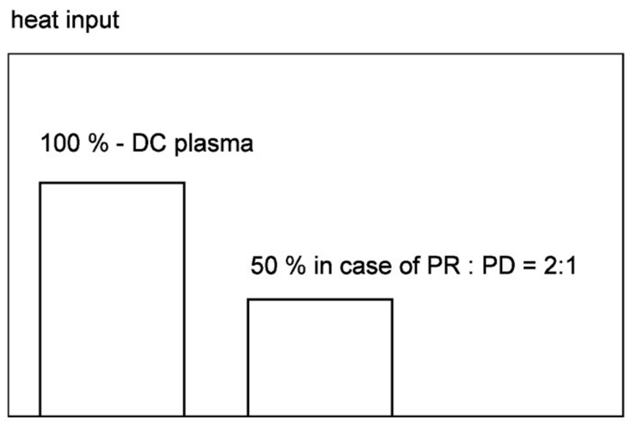

Figure 2: Pulsing effect on the heat input.

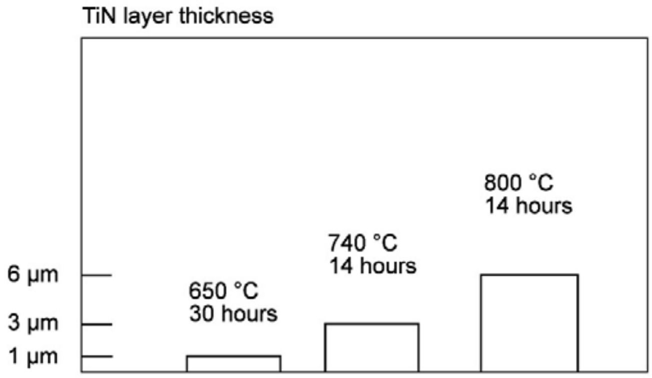

Figure 3: Time and temperature dependence on the TiN - layer thickness.

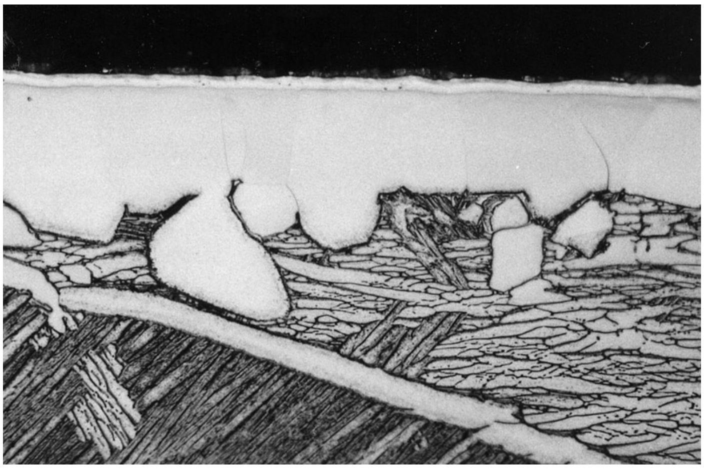
Figure 4: Nitrided structure, etched in 2% HF (IWT Bremen).

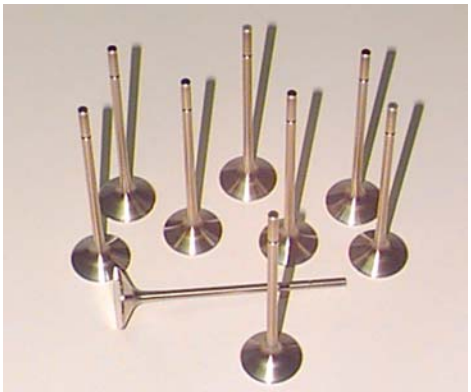
Figure 5: Titanium valves.


Figure 6: Steering rack.